Beam Condition Monitoring with Diamonds at CDF

The CDF diamond group:
Peter Dong, Charlie Schrupp, Rainer Wallny (UCLA)
Anna Sfyrla (University of Geneva)
Ricardo Eusebi, Rick Tesarek (Fermilab)

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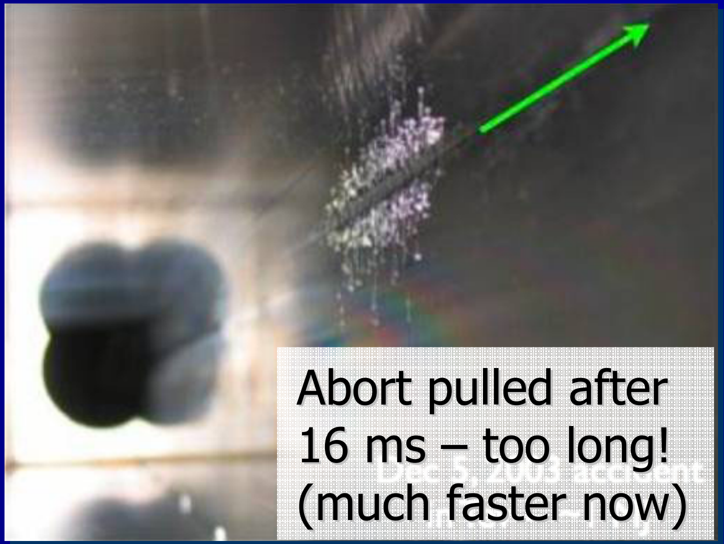
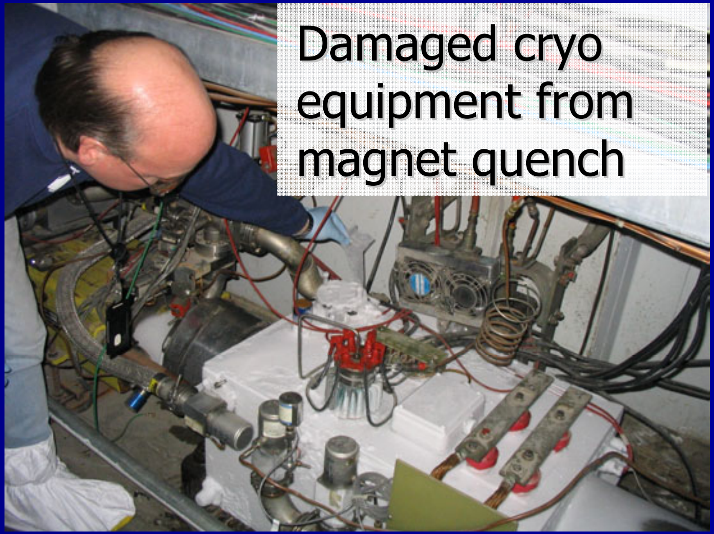
The Tevatron

- The world's highest-energy operation accelerator, with center-of-mass energy 1.96 TeV
- Stored beam energy of ~1.6 MJ – equivalent to a six-ton truck traveling at 60 mph, or two jelly donuts (Mike Syphers)
- In the last few years, rapidly increasing luminosity, thanks to the ongoing efforts of the Accelerator Division.
- The key to CDF and D0's physics results!

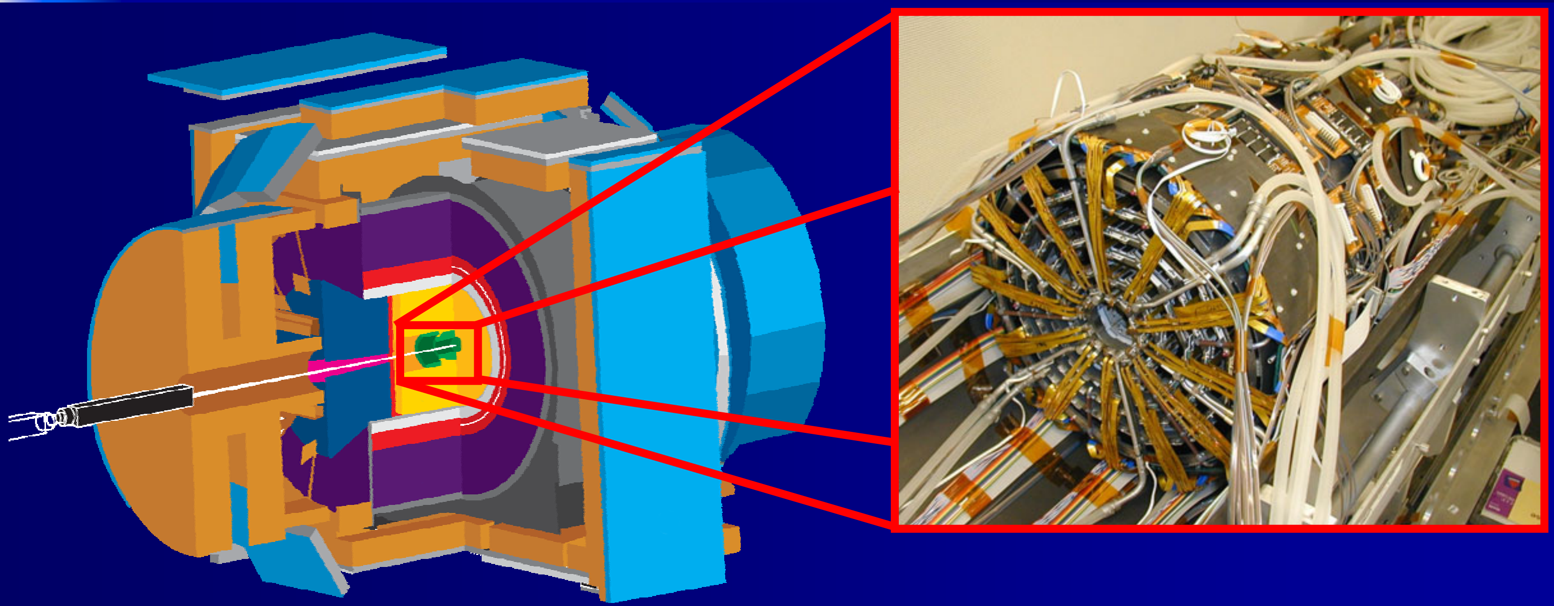
With great power comes…

- A powerful particle beam is potentially dangerous
- Sometimes things go wrong
  - Separator spark
  - Kicker prefire
  - RF station trip
  - Incorrect tuning
  - Electronics failure
- Unstable beam can damage Tevatron system components
- Beam must be aborted as soon as instability is detected





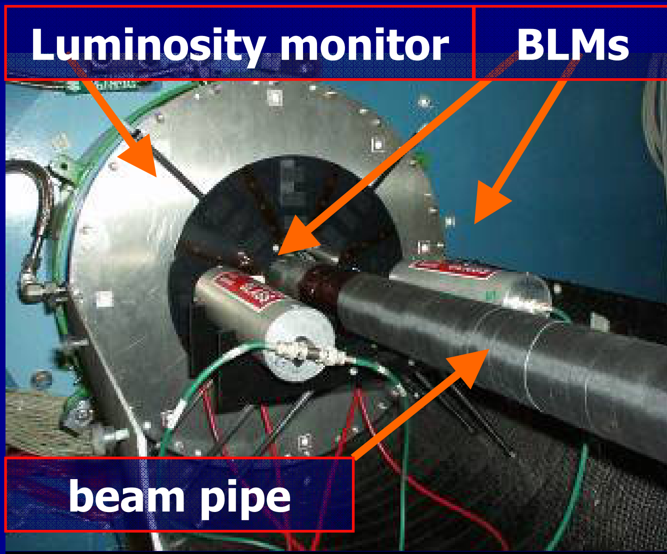
CDF and the silicon detector

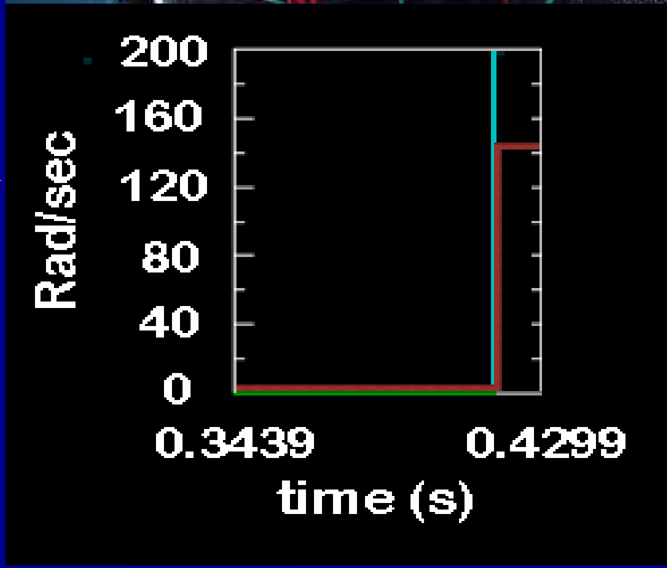


- Multi-purpose particle detector
- Silicon detector is key part, but also very delicate:
  - Close to beam (1.5 cm)
  - Vulnerable to beam accidents
  - Not accessible for replacement or maintenance
- Silicon must be protected to keep taking good data!

Current abort system

- Based on beam loss monitors (BLMs): argon-filled ionization chambers
- FIFO electronics with 210-μs bin width (10 revolutions of beam)
- Location limited by BLM size: very far (4.3m) from silicon detector
- 210 μs is too long; most "dirty" aborts look like this
- The system should be faster and closer to the silicon
- This is ideal for diamonds





Why diamond?

	Silicon	Diamond
Band gap [eV]	1.12	5.45
Electron mobility [cm²/Vs]	1450	2200
Hole mobility [cm²/Vs]	500	1600
Saturation velocity [cm/s]	0.8×10^7	2×10^7
Breakdown field [V/m]	3×10^5	2.2×10^7
Resistivity [Ω cm]	2×10^5	$>10^{13}$
Dielectric constant	11.9	5.7
Displacement energy [eV]	13-20	43
e-h creation energy [eV]	3.6	13
Ave e-h pairs per MIP per µm	89	36
Charge coll. dist. [µm]	full	~250

→ *Low $I_{leakage}$, shot noise*

Fast signal collection

→ *Low capacitance, noise*

→ *High radiation hardness*

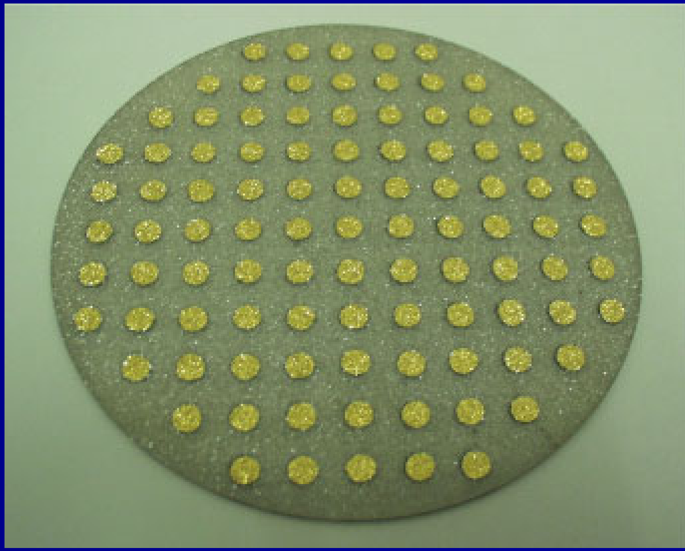
Smaller signals

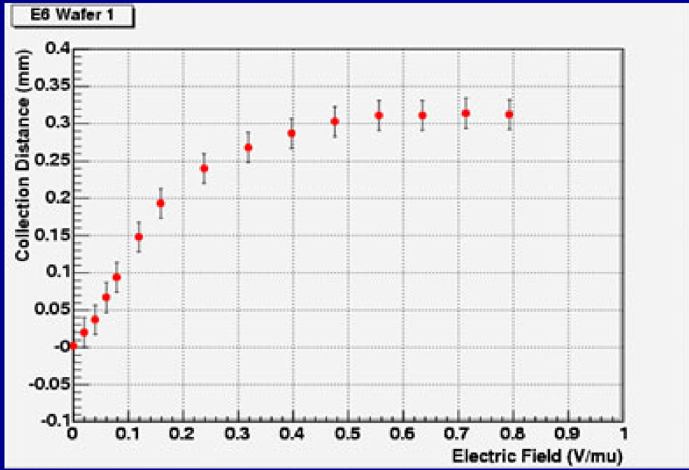
+ high thermal conductivity:

Room temperature operation

Polycrystalline CVD diamond

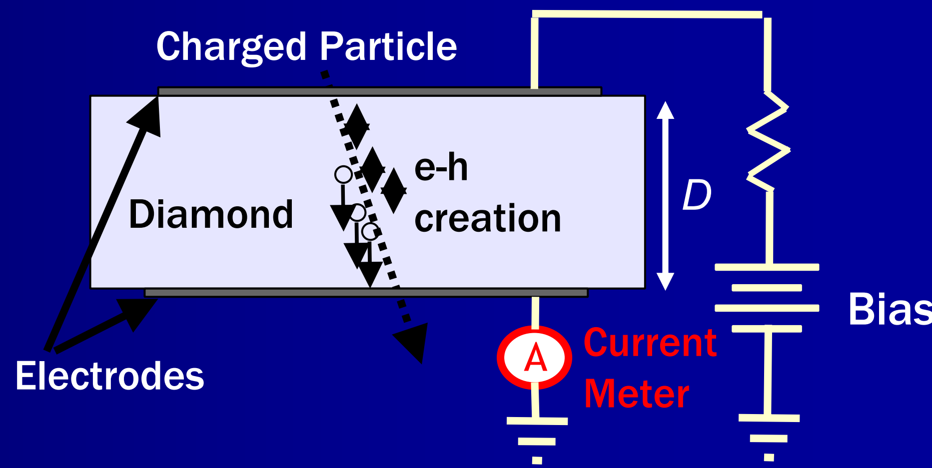
- Production studied by CERN RD42 collaboration
- Diamonds grown by chemical vapor deposition (CVD) process
- Now routinely grown more than 12 cm in diameter and 2 mm thick
- Finite charge collection distance (CCD)
  - Due to charge trapping (grain boundaries, impurities, etc.)
- Typical CCD ranges from 250 to 310μm
- CCD saturates at around 1 V/μm

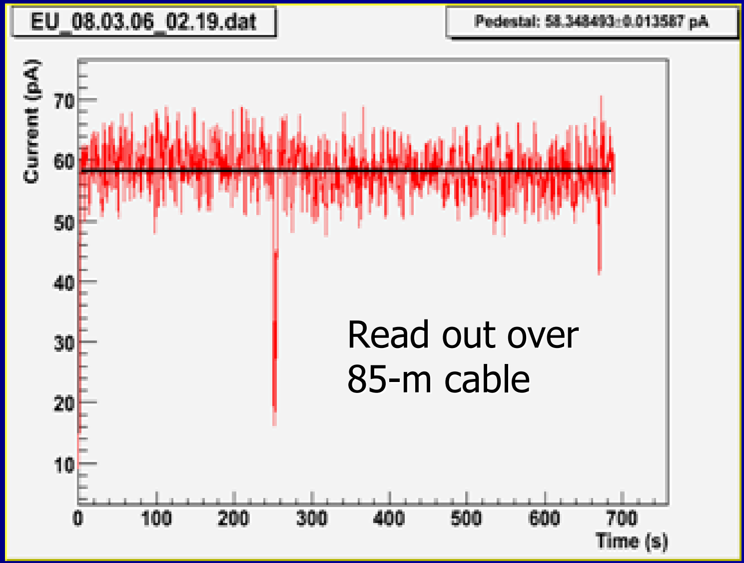




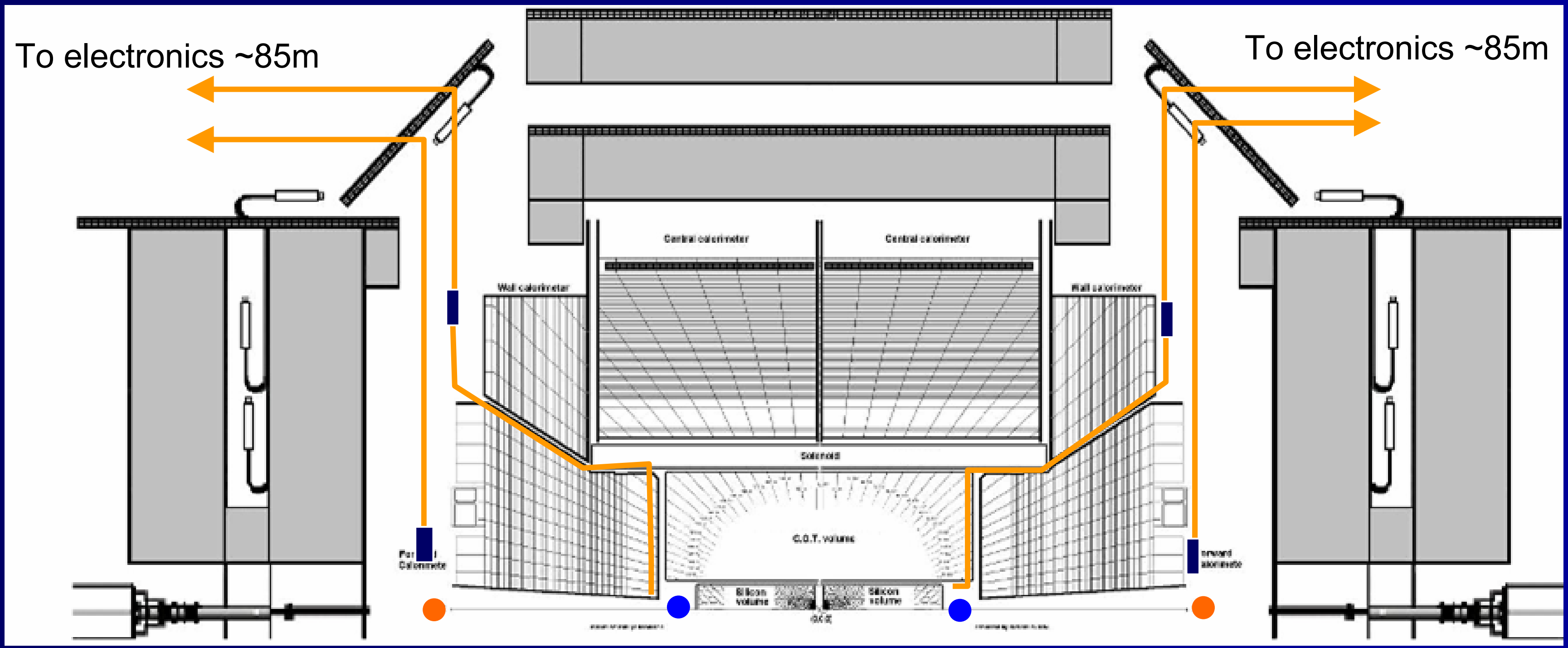
Diamond detectors

- Bias voltage applied across diamond
- ~500V for 500μm thick detector
- Charged particles generate electron-hole pairs that drift apart in electric field to electrodes
- DC-coupled radiation sensor:
  - Measure induced current
  - Leakage current of a few pA
- Acts as a solid-state ionization chamber



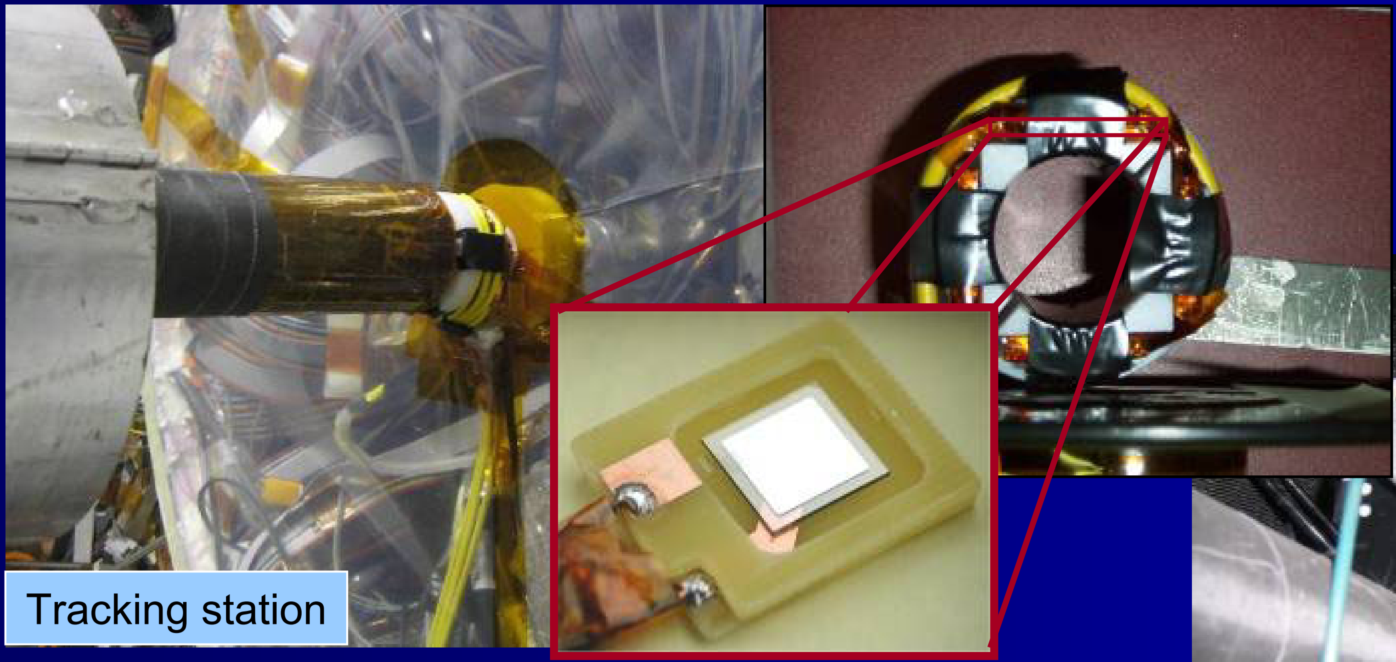


The CDF diamond BCM system

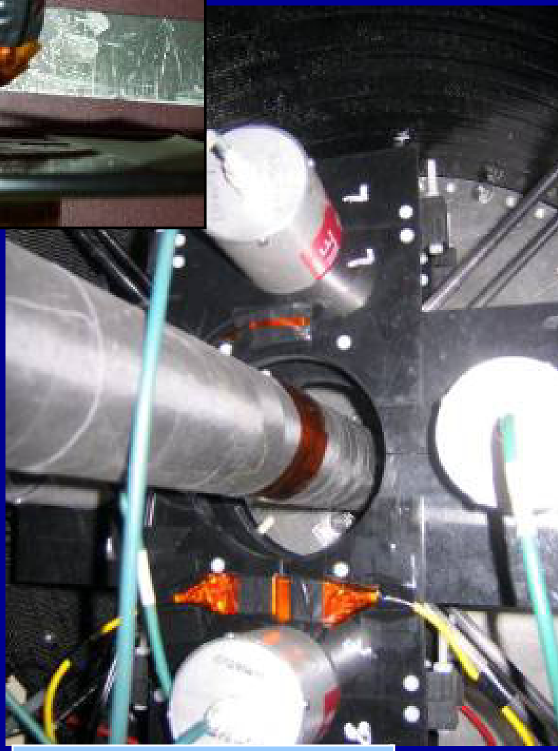


- 8 diamonds in the tracking volume for beam monitoring and aborts (blue dots): r = 2 cm |z| = 1.7 m
- 5 diamonds near the current BLMs for calibration (orange dots): r = 10.7 cm |z| = 4.3 m

Location of diamond sensors



Tracking station

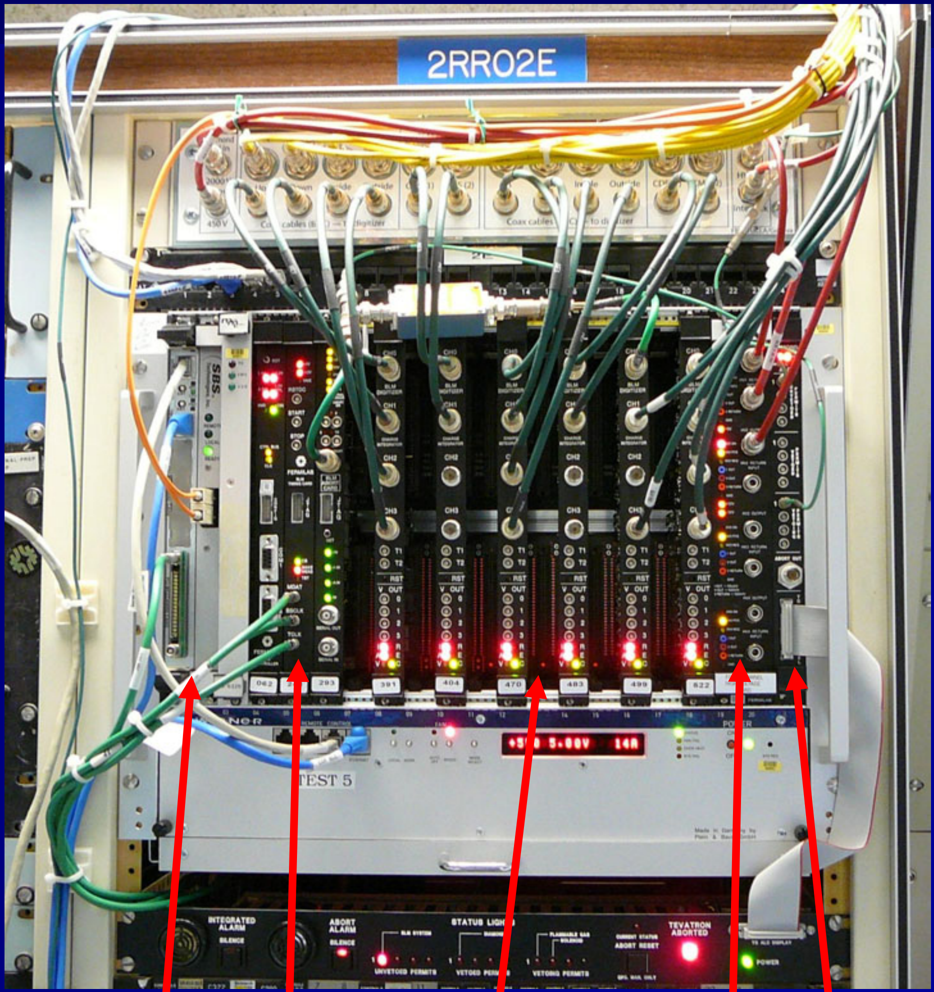


Calibration station

- 1-cm^2 diamonds with aluminum-based metallization, in G10 package with copper shielding – piggybacked on ATLAS diamond production.
- 85-m triaxial cable reads out to counting room

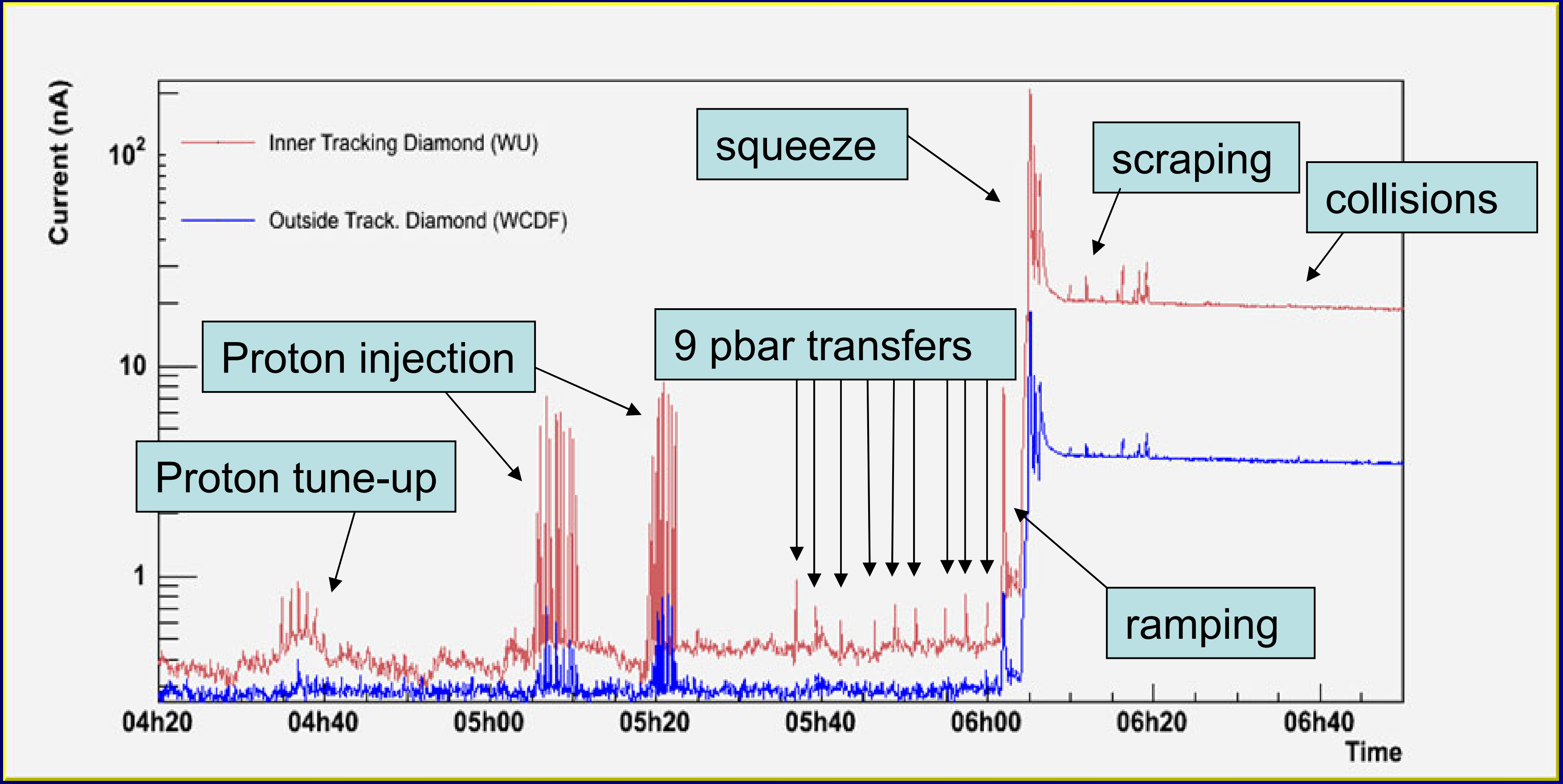
DAQ system

- Borrowed from Tevatron BLM upgrade (thanks to AD Instrumentation and PPD EE departments!)
- Integrates on multiple time constants for abort comparisons.
- Makes a reading every 21 μs (one Tevatron revolution)
- Provides turn-by-turn data after Tevatron abort.



Front-end CPU
Digitizer cards
HV card
Timing card, abort card
Interlock card

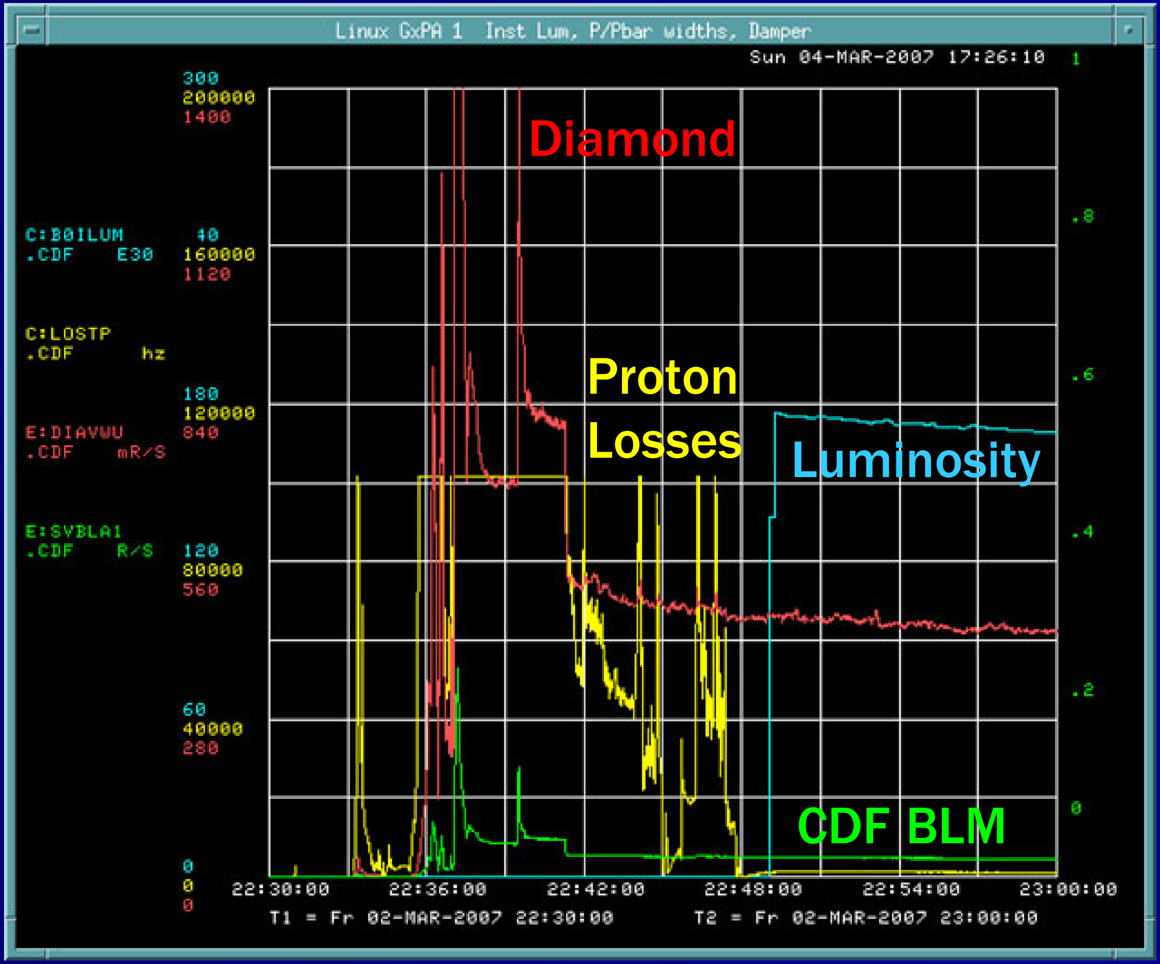
Shot setup: taking the pulse of the Tevatron



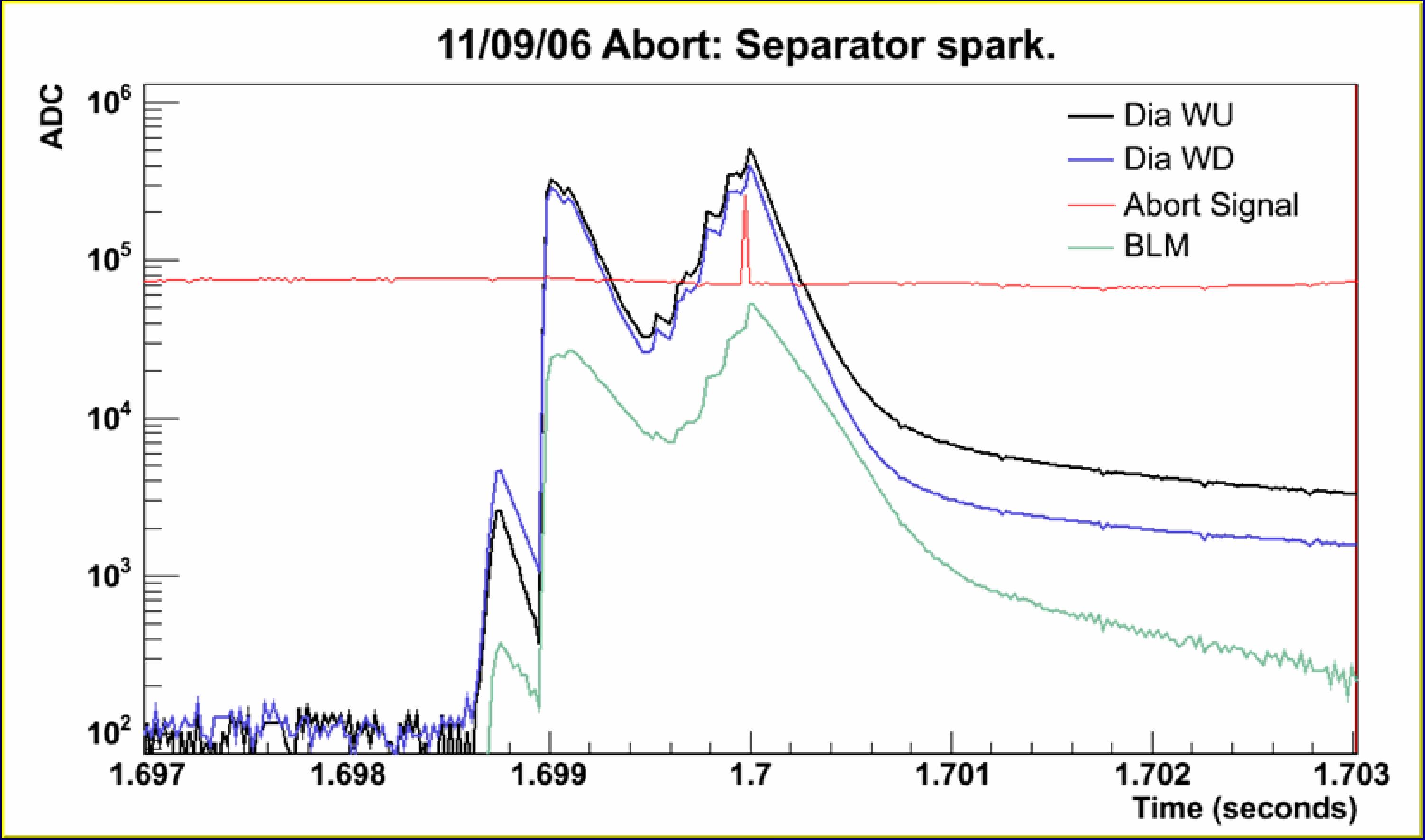
- Inner tracking diamonds are closer to the beam and have more sensitivity to accelerator events.

Online monitoring

- Monitor diamonds through Accelerator Control Network (ACNET).
- Data logged at 1 Hz
- Can see real-time plots at a few Hz



Buffer dump in case of abort

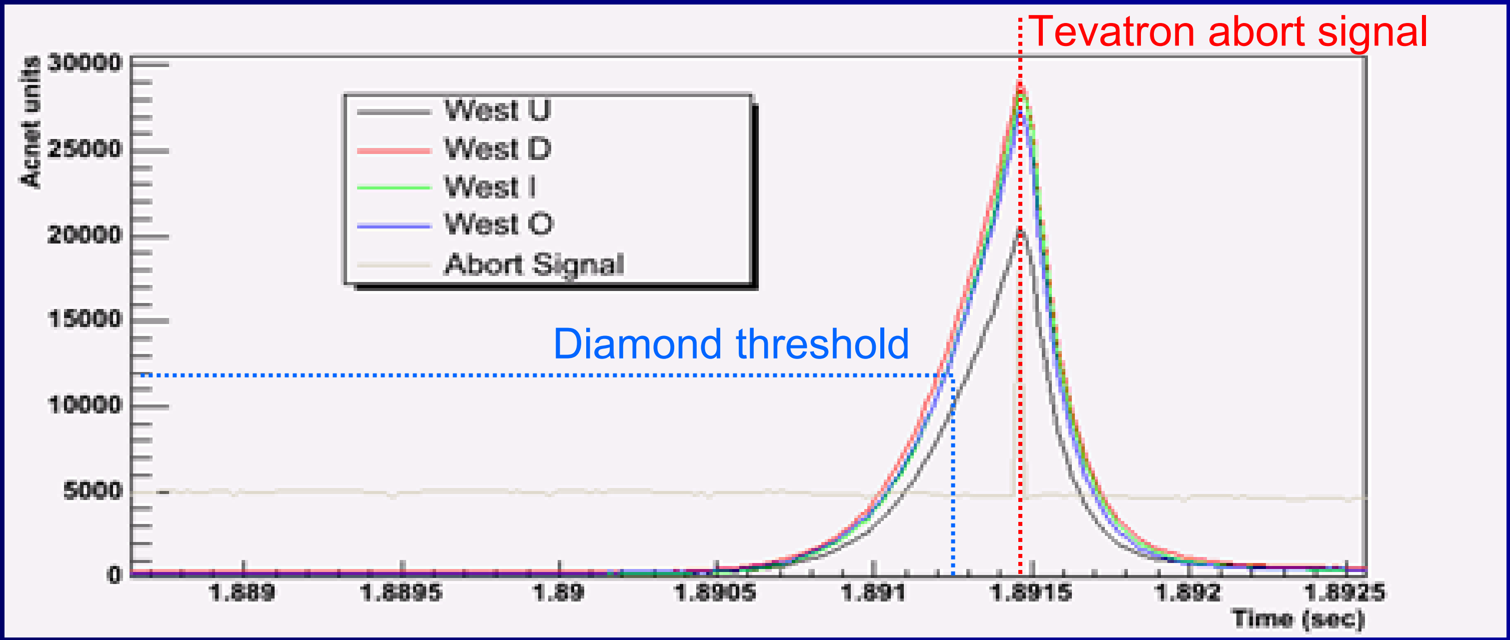


- Capable of seeing fine time structure in beam incidents.
- Should be able to pull the abort earlier.

Abort system

- Diamond abort system (being commissioned) allows the diamond system to pull Tevatron aborts when radiation is too high.
  - Uses Tevatron BLM abort card.
  - Can abort on both instantaneous and integrated doses.
  - Can assign multiplicity requirements for each abort threshold.
- Additional electronics prevent accidental aborts and protect the detector:
  - High voltage interlock that drops in case of flammable gas alarm.
  - Solenoid interlock prevents abort from being pulled when the solenoid is not at full field.

High-loss abort



- 20-μs buffer from a quench during scraping
- If diamonds had been used in abort, could have pulled it ~500 μs earlier
- Could potentially have avoided magnet quench, protecting hardware and reducing radiation damage to sensitive detectors.

Conclusions

- Diamond is now well established as a detector material in high-energy physics applications.
- CDF has the world's largest operational diamond BCM system, and the only one at a hadron collider
  - Can resolve 20-μs time structures using unamplified DC-coupled sensors
  - Beam abort capability nearly completed – readiness review this month!
- LHC experiments have built or planned similar systems

Acknowledgements

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- CDF: Dervin Allen, Mary Convery, Mike Lindgren, Aseet Mukherjee, Rob Roser, Willis Sakumoto, Ken Schultz, Peter Wilson, Bob Wagner, George Wyatt …
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- RD42: Harris Kagan
- And anyone else we missed – thanks!